

## COMMENTS ABOUT THE ORIGIN OF TOGA

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### ABSTRACT

The creation of the TOGA Program was closely related to the El Niño phenomenon and to scientific explorations about the rich spectrum of ocean current variations in the narrow equatorial wave guide. Not until the appearance of the strong El Niño episode of 1957-1958 were there sufficient evidences that El Niño was a large-scale phenomenon, and not a coastal feature. The discovery of the Equatorial Undercurrent in the Pacific in 1952, which was not predicted from the geostrophic balance that was essential to the explanation of so many ocean circulation features, provided a *raison d'être* for scientific explorations of the Equatorial Undercurrent.

### 1 INTRODUCTION

The scientific objectives of the Tropical Oceans Global Atmosphere (TOGA) Program, which occurred from January 1985 to December 1994, were

- (1) To gain a description of the tropical oceans and the global atmosphere as a time-dependent system in order to determine the extent to which the system is predictable, on time scales of months to years, and to understand the mechanisms and processes underlying its predictability;
- (2) To study the feasibility of modeling the coupled ocean-atmosphere system for the purpose of predicting its variations on time scales of months to years; and
- (3) To provide the scientific background for designing an observing and data transmission system for operational prediction if this capability is demonstrated by coupled ocean-atmosphere models,

The scientific objectives were developed in 1983 and 1984 in accord with ideas and technology occurring at the time. What were the scientific ideas and technology at the beginning of TOGA? What were the progressions of scientific ideas and technology that formed the basis of TOGA? Were other factors important in the development of TOGA? These questions will be explored in this paper, which, by its nature, represents a personal perspective of historical developments leading to the creation of TOGA.

Modern-day oceanography began with the 1872-1876 voyage of the H.M.S. *Challenger*. When the *Challenger* sailed through the tropical Pacific along approximately 150°W from Honolulu to Tahiti during August and September 1875 (Thurman, 1991), no El Niño was occurring (Quinn *et al.*, 1987). Even if there had been an El Niño, scientists aboard the *Challenger* would not have recognized any characteristics of the warm-water phenomenon. At that time, the El Niño was thought to be a local phenomenon associated with the coastal regions of South America and no sea surface temperature climatology existed to determine if the August-September 1875 sea surface temperatures were different than normal.

### 2 EL NIÑO AND TOGA

#### 2.1 1957-1958 El Niño

Each year, beginning in 1950, the California Cooperative Oceanic Fisheries Investigations (CalCOFI) made extensive biological, chemical and physical oceanographic measurements off the west coast of North America from the southern tip of Baja California to the Columbia River. As a result of the time series measurements, unusual conditions were noted in the circulation off California during 1957 and 1958. (Contrary to recent popular opinion, the El Niño of 1957-1958 was not responsible for the dramatic decline in the California sardine fishery, in which the catch was small each year from 1953 to 1958 compared to 1952 or 1959 (CalCOFI, 1960)). A CalCOFI symposium, entitled "The Changing Pacific Ocean in 1957 and 1958", occurred in Rancho Santa Fe, California, on 2-4 June 1958 (Sette and Isaacs, 1960) to evaluate the unusual conditions. (The first day of the Symposium coincided with the death of Townsend Cromwell in an airplane crash enroute to join an oceanographic expedition to the tropical Pacific). Other unusual environmental conditions had occurred during 1957-1958: Canton Island, usually dry, was covered with vegetation; Hawaii had its first recorded typhoon; warm water invaded the coastal area of Peru; sea ice at Point Barrow retreated very early; the Aleutian Low was intensified; winds along California were weak; and sea surface temperatures over the eastern North Pacific were 3°C higher

than normal (Sette and Isaacs, 1960). Participants included many of the world's leading oceanographers and meteorologists, but no satisfactory model was developed that related the diverse oceanographic and meteorological conditions over a large portion of the globe.

Bjerknes (1966), in examining the results of the CalCOFI symposium (Sette and Isaacs, 1960), proposed a novel idea that the invasion of warm water off the coast of South America, which had given rise to the definition of El Niño, was not caused by local ocean-atmosphere interactions. He speculated that El Niño was caused by a reduction of the easterly winds along the equator. The subsequent decrease in the east-west pressure gradient would allow water above the thermocline to flow eastward. In addition to heat advection from the western warm-water pool, the near-surface temperature in the eastern tropical Pacific would also increase because of a reduction in upwelling. He proposed that an anomalous atmospheric heat source in the eastern tropical Pacific would alter the Hadley circulation, including a strengthening of the Aleutian Low and a weakening of the Icelandic Low. The primary triggering mechanism of the temperature anomaly in the eastern Pacific remained a mystery for several more years.

Rowntree (1972), while visiting the National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL), used the newly developed GFDL atmospheric general circulation model to substantiate the Bjerknes (1966) hypothesis about teleconnections between a sea surface temperature anomaly in the eastern tropical Pacific and middle latitude atmospheric conditions. The numerical experiment was extremely successful, confirming Bjerknes hypothesis. Rowntree's experiment was followed by others (Julian and Chervin, 1978; Keshavamurty, 1982; Shukla and Wallace, 1983; Blackmon *et al.*, 1983) to demonstrate the sensitivity of global atmospheric general circulation model simulations to the magnitude and location of prescribed anomalous sea surface temperature patterns in the eastern tropical Pacific. The amount of predictability of global atmospheric circulation caused by tropical Pacific sea surface temperature variations became a TOGA objective.

## 2.2 1972-1973 El Niño

The El Niño of 1972-1973 had a great influence upon the price of agricultural products in many countries because the Peruvian fishery catch, which at the time was the world's largest, dropped from 12 million tons to 2 million tons. Nearly all of the Peruvian fishery was ground into fish meal and distributed worldwide as a protein source for poultry and livestock. The alternate source of protein for animals was soybean, in which the largest supplier was the United States where the crop in 1973 was severely reduced because of heavy rains attributed to the El Niño.

It seems fortuitous that two to three years before the onset of the 1972-1973 El Niño, there was a resurgence of scientific interest in theoretical aspects of equatorial circulation. A previous burst of activity occurred in the 1950s after the 1952 discovery of the Equatorial Undercurrent (Cromwell *et al.*, 1954), which culminated in a series of papers (Deep-Sea Research, 1960) that attempted to explain the dynamical behavior of the Equatorial Undercurrent. At that time, the explanations assumed steady-state motion. The renewed interest in equatorial ocean circulation focused on time-dependent motions. Blandford (1966) first examined the theoretical aspects of time-dependent motion along the equator, emphasizing mixed-Rossby gravity waves. Moore (1968) first explained the dynamics of the Kelvin wave along the equator, but the result was not widely published for some time (see Moore and Philander, 1977). Lighthill (1969) provided a theoretical foundation for the generation of low-latitude ocean currents driven by non-steady winds. Godfrey (1975) first proposed that an internal downwelling equatorial Kelvin wave, which would be created when an easterly wind stress had decreased, would signal the arrival of warm water in the eastern Pacific or El Niño conditions. Hickey (1975) showed that the correlations between fluctuations of surface wind stress, sea level, and sea surface temperature were high in the equatorial Pacific, but was unable to describe a cause-and-effect relationship between the variables, perhaps because she was unaware of the work of Godfrey (1975). The next year, Hurlburt *et al.* (1976) and McCreary (1976) quantitatively described many features of the equatorial downwelling Kelvin wave that would be produced by a reduction in the easterly wind. In addition, McCreary (1976) demonstrated that temporal variations of the wind stress within 5° of the equator was substantially more important in creating equatorial Kelvin waves than the wind stress between 5° and 20° from the equator. McCreary's (1976) result had important consequences on the design of the TOGA moored buoy array (Hayes *et al.*, 1987). Wyrki (1975) provided a mechanism for the 1972-1973 El Niño by combining the conceptual model by Bjerknes (1966), theoretical result from Godfrey (1975), observational results from Hickey (1975) and Ramage (1975), and suggested an important characteristic about the surface wind stress. Wyrki (1975) proposed that a period of stronger-than-normal easterly winds would buildup excessive warm water in the western Pacific, which would increase the east-west slope of sea level along the equator; upon relaxation of the easterly wind stress, the warm water would flow eastward along the equator as a Kelvin wave, and the thermocline in the eastern Pacific would deepen, allowing warm water to accumulate. Observations of Kelvin wave propagation along the Pacific equator did not occur for several more years (Knox and Halpern, 1982; Eriksen *et al.*, 1983).

The appearance of a conceptual model about a generation mechanism of El Niño resulted in new observational programs in the tropical Pacific. The U.S. National Science Foundation (NSF)-supported NORPAX Program expanded its objective to include ocean-atmosphere interactions in the central tropical Pacific. In about 1974, Klaus Wyrki took over the maintenance of the island sea level gauge network from NOAA, and rapidly expanded the network throughout the tropical Pacific for studies of climate variations (Wyrki, 1979). Klaus Wyrki, Chair of the NORPAX Executive Council,

encouraged the Council to consider a SOP XBT network to be the oceanographer's **radiosonde** array. in the **late 1970s**, the NORPAX Program, in collaboration with institutions in Australia and New Caledonia, expanded the North Pacific ship-of-opportunity (SOP) expendable bathythermograph (XBT) project into the tropical Pacific (White *et al.*, 1985). The 1979-1980 NORPAX Expedition demonstrated that island sea level measurements provided a reliable index of the geostrophic transports of the tropical currents (Wyrki *et al.*, 1981), and the annual cycle of oceanographic conditions in the tropical central Pacific Ocean was described (Wyrki and Kilonsky, 1984), i. e., the ocean climatology was, for the first time, known. Many measurements begun during the NORPAX Program were continued under the auspices of the Pacific Equatorial ocean Dynamics (PEQUOD) Experiment. Further to the east, near 110°W, the NOAA Equatorial Pacific Ocean Climate Studies Program (EPOCS) began in 1979 a long-term study of equatorial Pacific ocean-atmosphere interactions and their influence upon global climate.

### 2.3 1982-1983 El Niño

By 1982, El Niño was considered to be a large-scale oceanic adjustment to a relaxation of the westward surface wind stress. Rasmussen and Carpenter (1982) had defined the average El Niño to be associated with a westward propagating sea surface temperature anomaly. Also, satellite technology enabled sea surface temperature to be measured frequently and routinely throughout the tropical Pacific. Then, why did the onset of the 1982-1983 El Niño escape detection for several months? The easterly wind stress had not strengthened for a sufficiently long time interval; in fact, the easterly wind stress merely relaxed. The sea surface temperature anomaly did not move westward; it moved eastward. The anomalously high values of the satellite-derived sea surface temperature measurements associated with the El Niño were discarded as false because of the uncertainty about the reliability of the new kind of measurement (Halpern, 1984).

At the time of the 1982-1983 El Niño, oceanographic and meteorological measurements were being conducted throughout the eastern equatorial Pacific under the auspices of the EPOCS program and throughout the central Pacific by the PEQUOD Experiment. The central objective of both EPOCS and PEQUOD was observations of equatorial wave dynamics. It was serendipitous that circulation changes caused by the El Niño were observed for the first time in the central and eastern Pacific far removed from land (Firing *et al.*, 1983; Halpern *et al.*, 1983), including effects on the biological environment (Feldman *et al.*, 1984; Barber and Chavez, 1986). The magnitude of the observed variations associated with the El Niño could be interpreted with respect to normal conditions because NORPAX and EPOCS had conducted studies of the annual cycle of oceanographic conditions. The first comprehensive collection of numerous preliminary results and ideas, which involved the atmosphere and ocean, and physics, chemistry and biology, associated with the 1982-1983 El Niño was published during the El Niño in February 1983 in the *Tropical Ocean-Atmosphere Newsletter (TOAN)*, which, at the time, had a worldwide distribution greater than 1300 recipients. The TOAN represented an effective medium to rapidly distribute initial results to scientists throughout the world. The unusual worldwide environmental conditions that accompanied the El Niño were estimated to have caused agricultural, fisheries, and societal infrastructural damages of about \$US9x10<sup>9</sup> (1983 dollars). The 1982-1983 El Niño episode represented an exciting intersection of scientific and societal objectives: can science contribute to improved forecasts of El Niño, which became the goal of TOGA.

The inability to monitor the development of the 1982-1983 El Niño caused a fundamental change in attitude of NOAA towards ocean science, as then practiced in the equatorial Pacific. During a telephone-based conference in late November (or early December) 1982 among the members of the EPOCS Executive Council, Joseph Fletcher, Director of EPOCS and Director of the NOAA Environmental Research Laboratory, insisted that never again would an El Niño occur undetected. Thus, the policy for real-time monitoring of oceanographic and surface meteorological variables from moored and drifting buoys was firmly established. Real-time transmission of moored-buoy wind and temperature measurements was demonstrated in 1983 (Halpern *et al.*, 1984). In January 1983 the EPOCS Program commissioned a report, under the direction of the author, to describe an in situ oceanographic monitoring system for the eastern equatorial Pacific. The EPOCS Report ("Interannual Sea Surface Temperature Variations in the Equatorial Pacific", unpublished, 1983) indicated that real-time data acquisition from an array of instrumented surface moorings positioned throughout the data-sparse region of the central equatorial Pacific could monitor the generation and eastward movement of the characteristic El Niño anomalies in the surface wind, sea surface temperature, and upper ocean current and thermal fields. Expansion of the moored array into the western Pacific was an important consideration for an effective El Niño detection system. Discussions between the U.S. and People's Republic of China, which had been initiated in 1982 by the author, to establish a moored-buoy station at 165°E were progressing; in 1985 the moored station was established and continued for nearly five years. Because of the sparseness of in situ subsurface observations, progress to create operational descriptions of subsurface thermal and flow fields would have been extremely limited had not a reliable ocean general circulation model been developed at this time (Philander and Seigel, 1985). While a substantial amount of work remained to be done in merging data and models and to improve understanding of the response of the ocean to atmospheric forcing, a permanent El Niño detection system was being developed as early as 1983 (Halpern *et al.*, 1984).

During the pre-TOGA years, the foundations of the TOGA observing system (Halpern, 1990), operational hindcasts of subsurface oceanographic conditions (Lectmaa and Ji, 1989), and El Niño predictions (Inoue and O'Brien, 1984) were established. operational hindcasts of monthly oceanographic conditions in the tropical Pacific involved participation from many countries throughout the Pacific through the auspices of the Pacific Ocean Climate Studies Panel of the Committee

on Climatic Changes in the Ocean (CCCCO), which was jointly sponsored by the Intergovernmental oceanographic Commission (IOC) and the Scientific Committee for oceanic Research (SCOR).

### 3 EQUATORIAL UNDERCURRENT AND TOGA

The EUC represents the most prominent feature in the equatorial wave guide, in which there is an extremely rich spectrum of motions. However, in the context of the historical development of TOGA, the EUC also represents an environmental barrier for continuous measurements of upper ocean current and temperature and surface wind in order to detect El Niño conditions. The engineering difficulty in maintaining a surface mooring on the equator in water depths of 4-5 km arises from the stresses on the mooring line created by the shears of strong currents in the upper ocean. In the Pacific, the eastward-flowing EUC has a maximum speed greater than 1 m S-l at about 100 m depth and occurs beneath the westward-flowing South Equatorial Current, which has a maximum speed of 1 ms<sup>-1</sup> at the surface. The difficulty to record time-series measurements beneath a surface buoy moored at the equator was demonstrated in 1971 by Taft *et al.* (1974). The difficulty was overcome by adding a faired material to the upper 300 m of the mooring line, which is a technique to reduce the current drag on the wire that the author first observed in 1974 during the R.R.S. *Discovery* cruise in the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE) where a faired wire was used to tow a profiling conductivity-temperature-depth (CTD) instrument. The first Pacific-wide array of tautly-moored surface buoys, each of which had 5-7 current meters mounted in the mooring line above 250 m depth, was established in 1979 during the Global Weather Experiment when upper ocean temperature and current measurements were recorded along the equator at 165°E, 152°W and 110°W (Halpern, 1980). Thus, the technology required to record reliable surface wind and other meteorological variables and upper ocean current and temperature observations continuously for long periods at the equator was employed routinely in the Atlantic (Weisberg, 1984) and Pacific (Halpern, 1987) by the time of the start of TOGA.

### 4. SUMMARY

The TOGA Program was a success because scientific objectives stated at the start of the program were successfully completed. Scientific objectives were realistic and doable because of previous scientific and engineering accomplishments. Scientific objectives were associated with an internationally societal-relevant phenomenon, which is very important for a program designed to occur for many years because it enables the program to increase its resources to accomplish new ideas. The TOGA Program created operational subsurface oceanography (as distinct from marine surface measurements recorded under the auspices of the Integrated Global ocean Observing System, which is cosponsored by IOC and the World Meteorological Organization), implemented seasonal-to-interannual predictions of oceanographic and meteorological conditions, and conducted several process-oriented ocean-atmosphere interaction studies to improve model parameterization of sub-grid size scale processes. Perhaps, the ultimate legacy of the TOGA Program is the estimated ten-times increase in the number of researchers involved in TOGA-type research in 1995 compared to 1985.

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